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(54) **METHOD AND APPARATUS TO ASSESS THE THERMAL DAMAGE CAUSED TO A PCD CUTTER USING CAPACITANCE SPECTROSCOPY**

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CPC G01N 27/22
See application file for complete search history.

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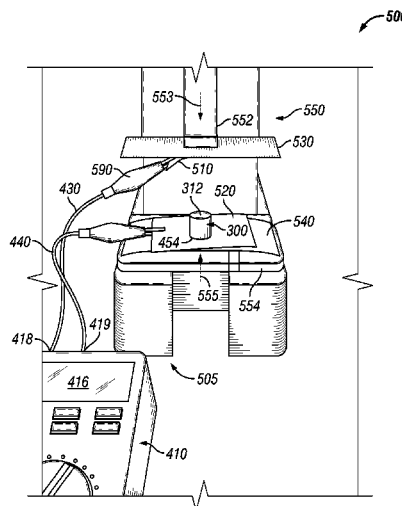
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(57) **ABSTRACT**

A method and apparatus for non-destructively determining the wear resistance of an ultra-hard polycrystalline structure after being coupled to a downhole tool using capacitance measurements. The apparatus includes a capacitance measuring device having a positive and negative terminal, a leached component comprising a polycrystalline structure that has been coupled to a downhole tool, a first wire, and a second wire. The first wire electrically couples the positive terminal to a surface of the leached component and the second wire electrically couples the negative terminal to a surface of the downhole tool. The capacitance is measured for the leached component one or more times and compared to a calibration curve that shows a relationship between capacitance values and wear resistance, thereby allowing determination of an estimated wear resistance for the polycrystalline structure.

18 Claims, 10 Drawing Sheets



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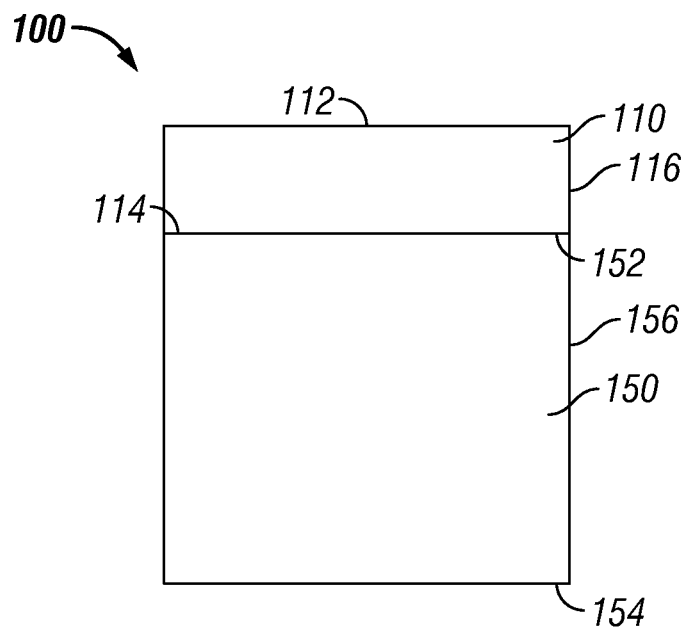


FIG. 1
(Prior Art)

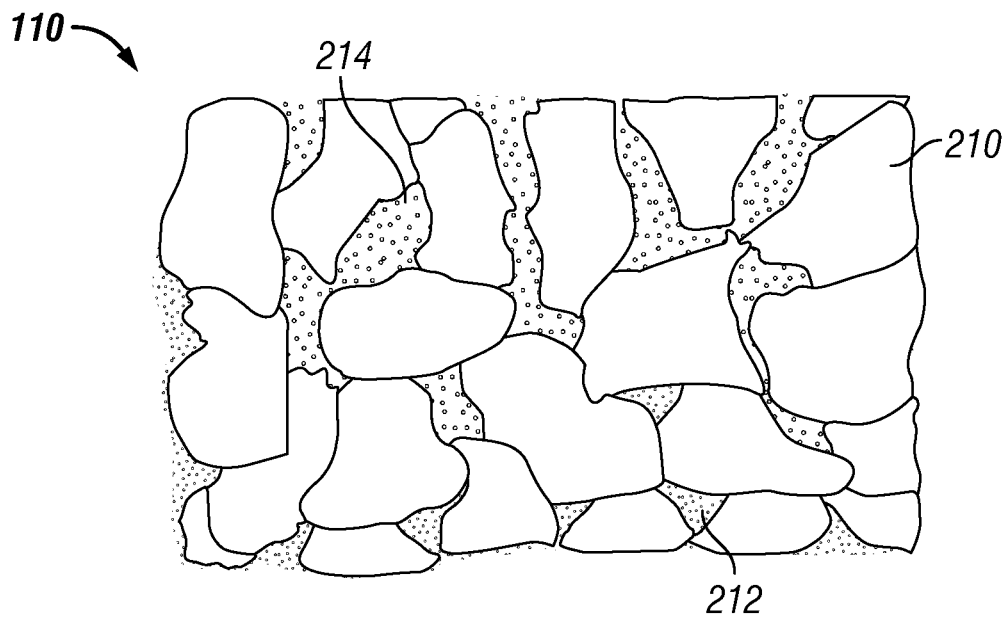


FIG. 2
(Prior Art)

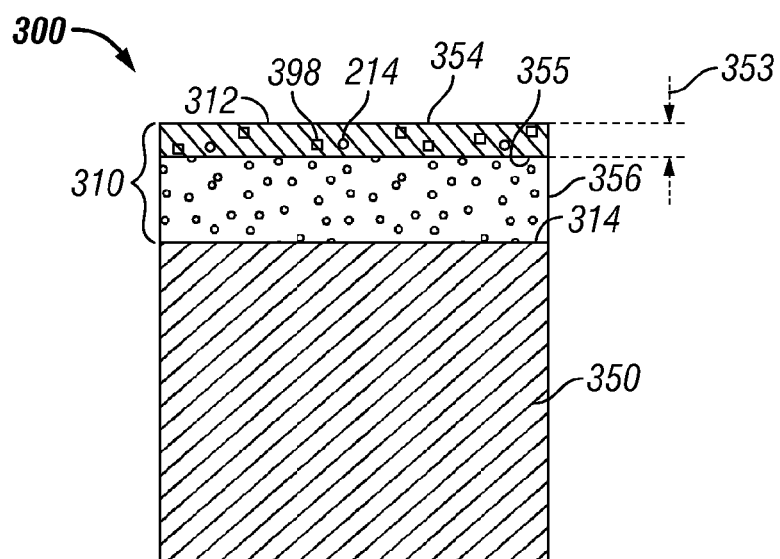


FIG. 3
(Prior Art)

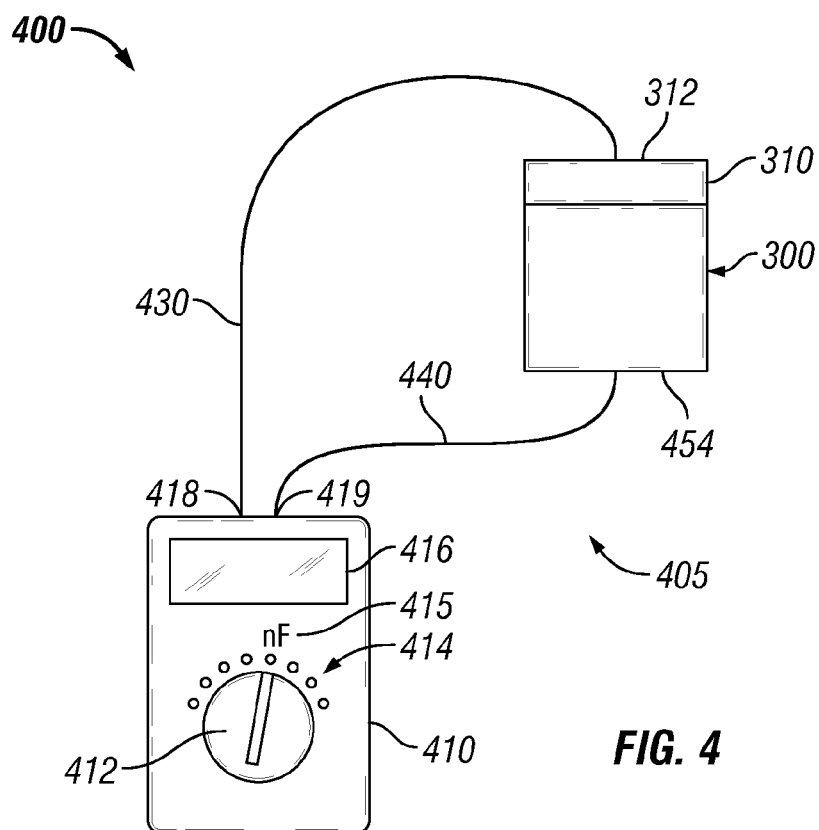


FIG. 4

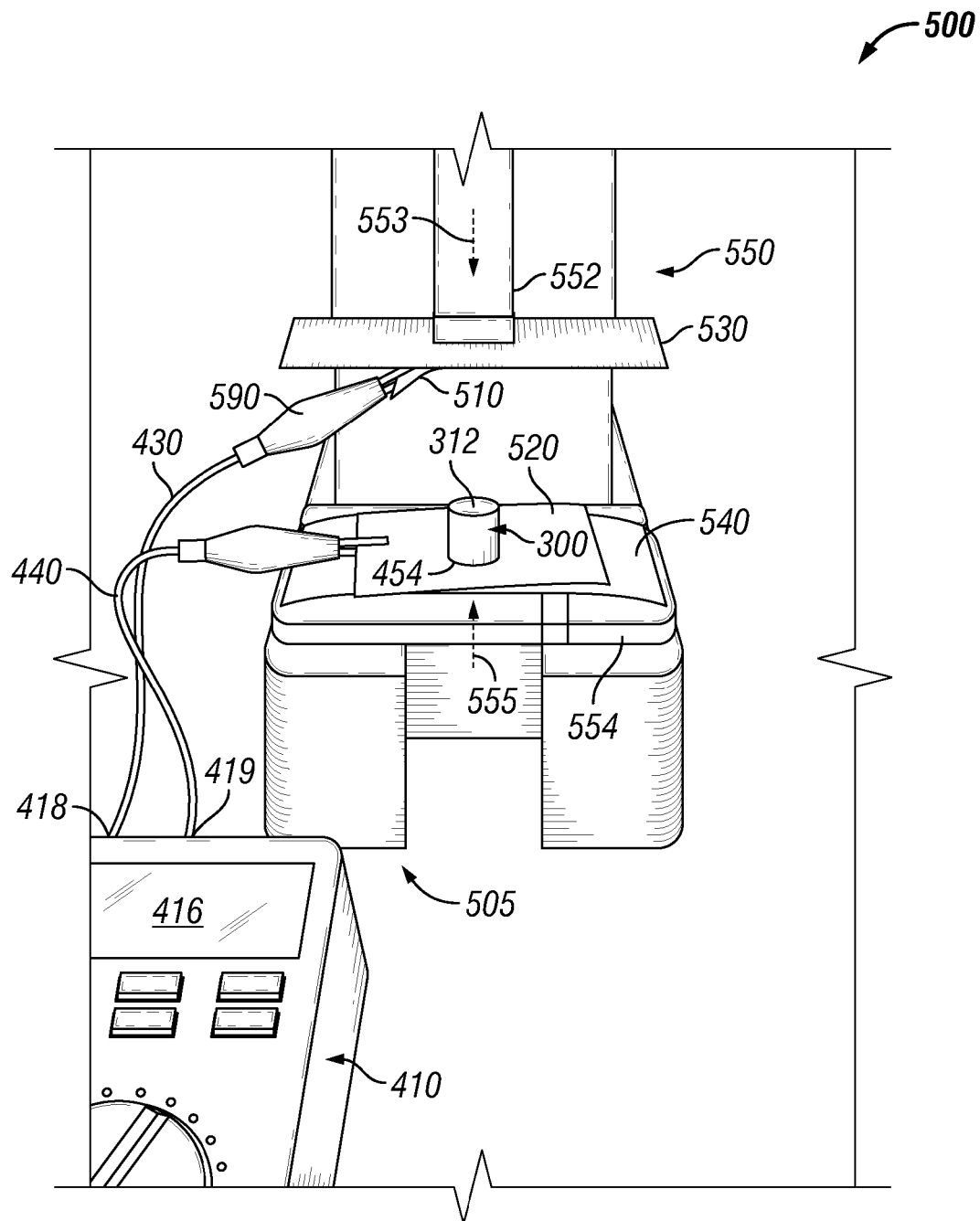
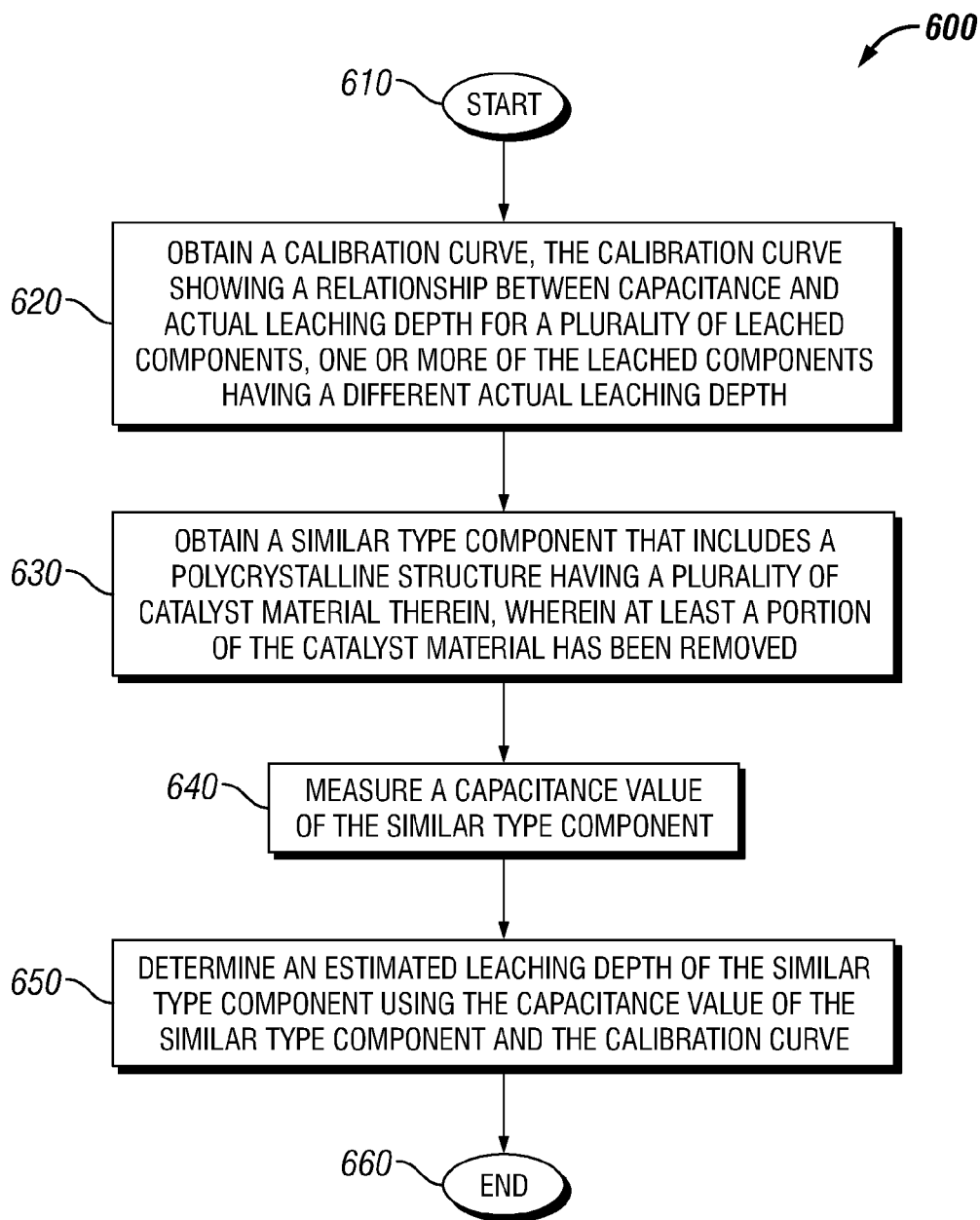


FIG. 5

**FIG. 6**

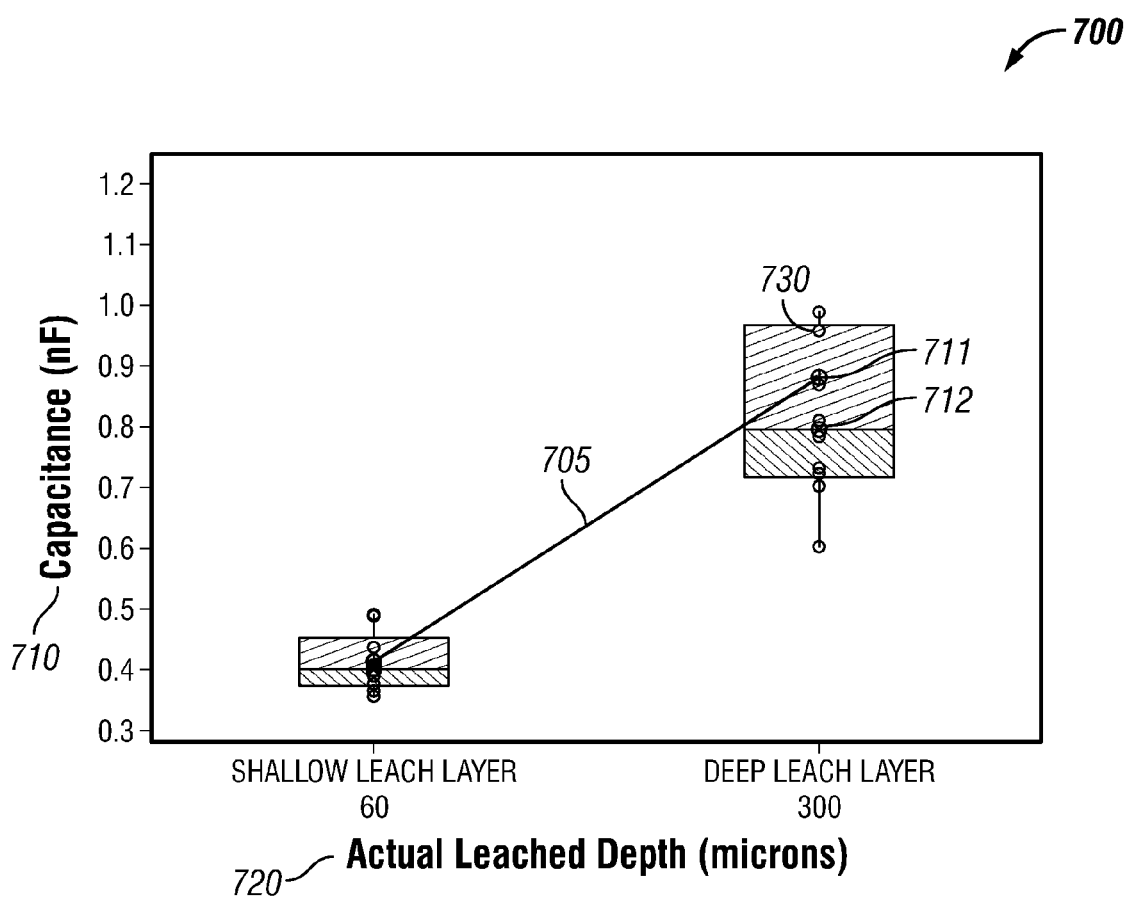
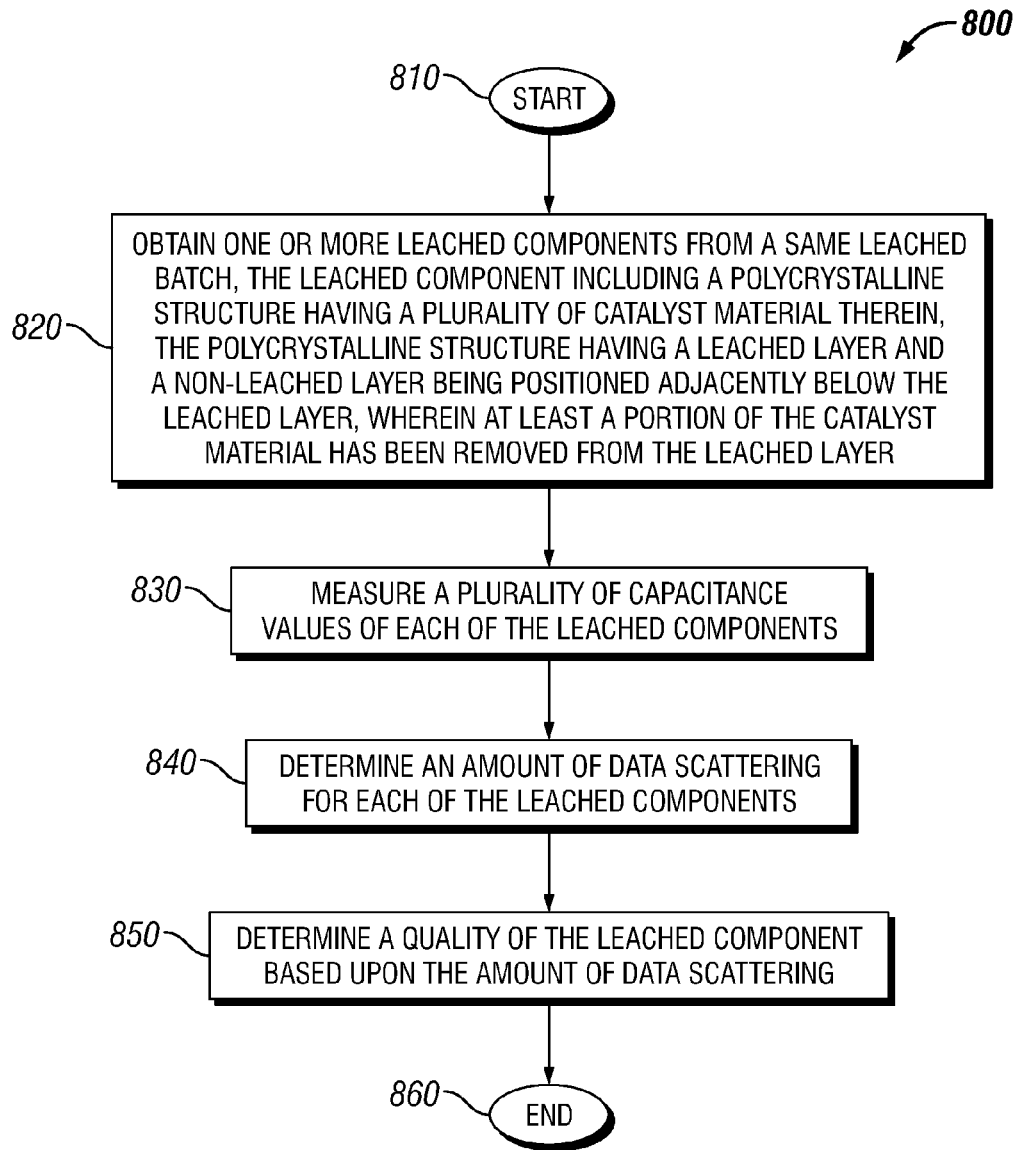


FIG. 7

**FIG. 8**

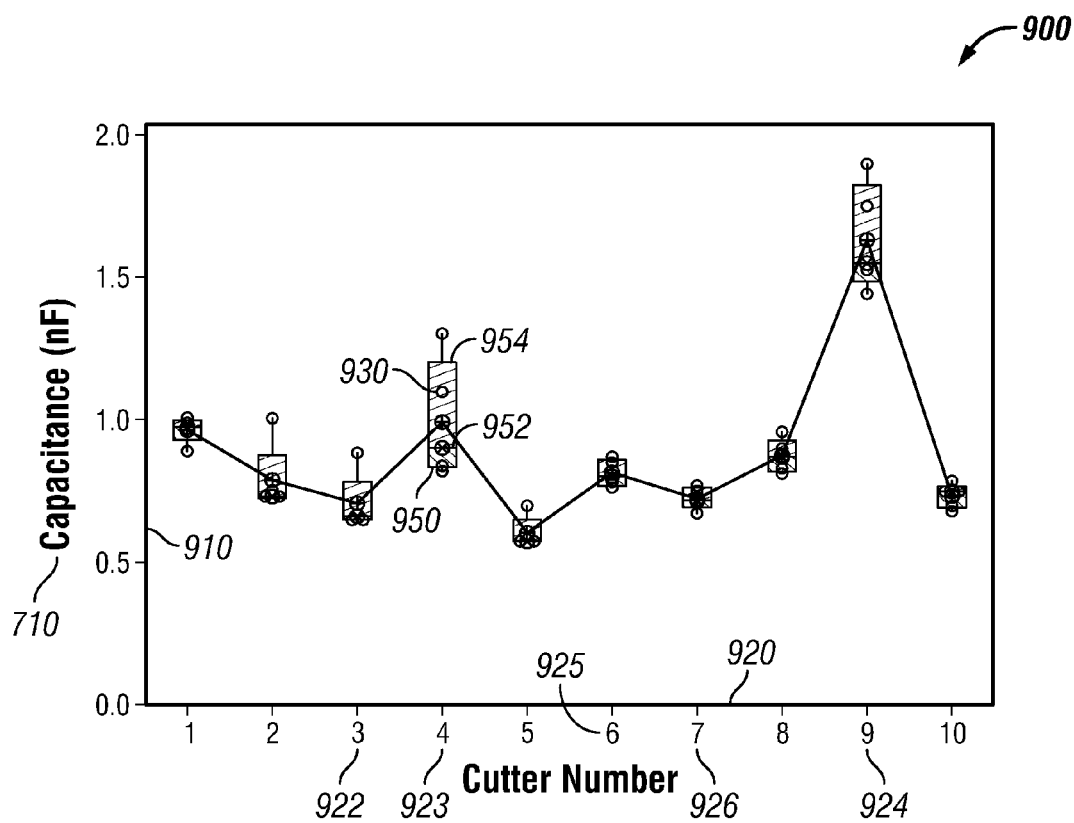


FIG. 9

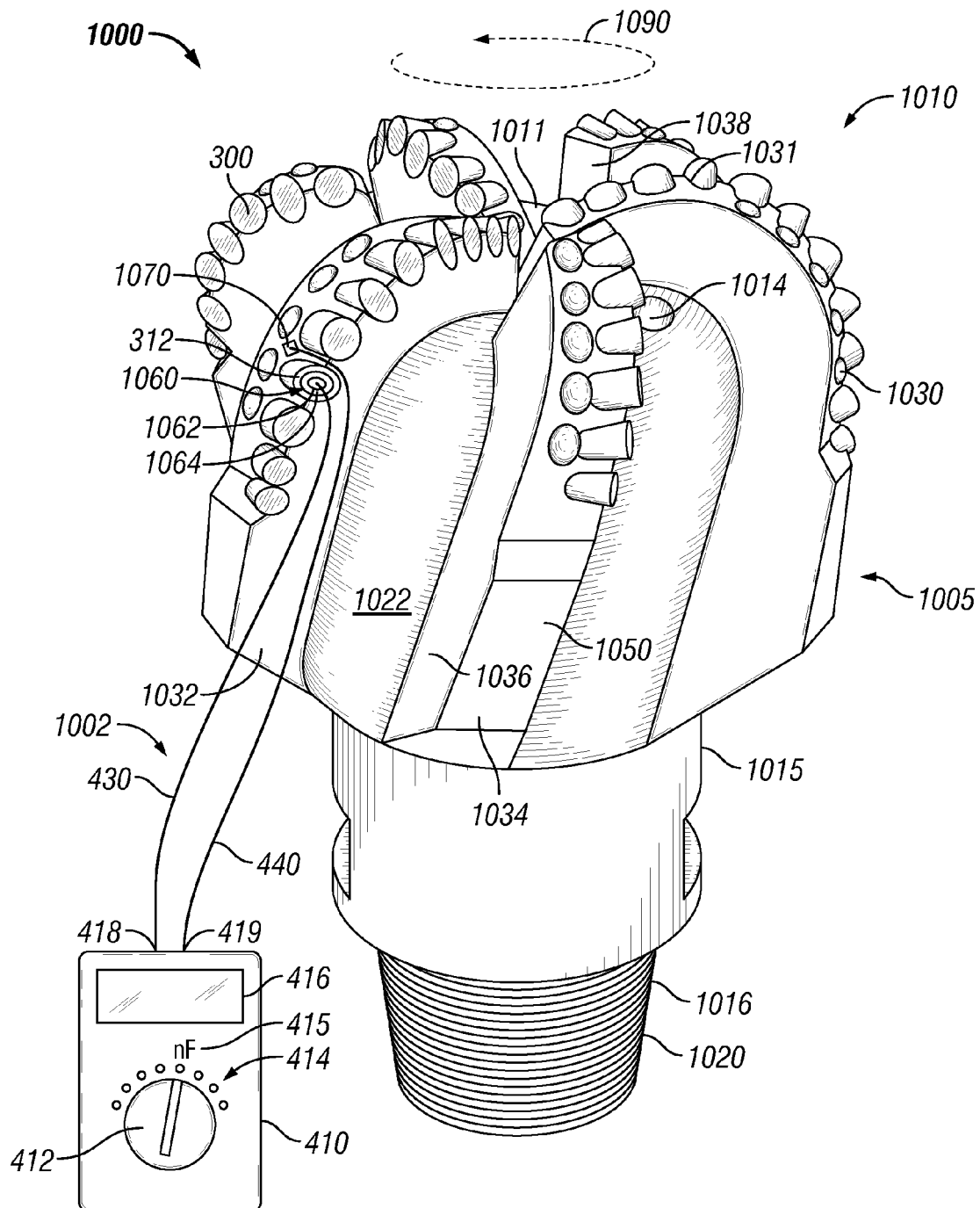
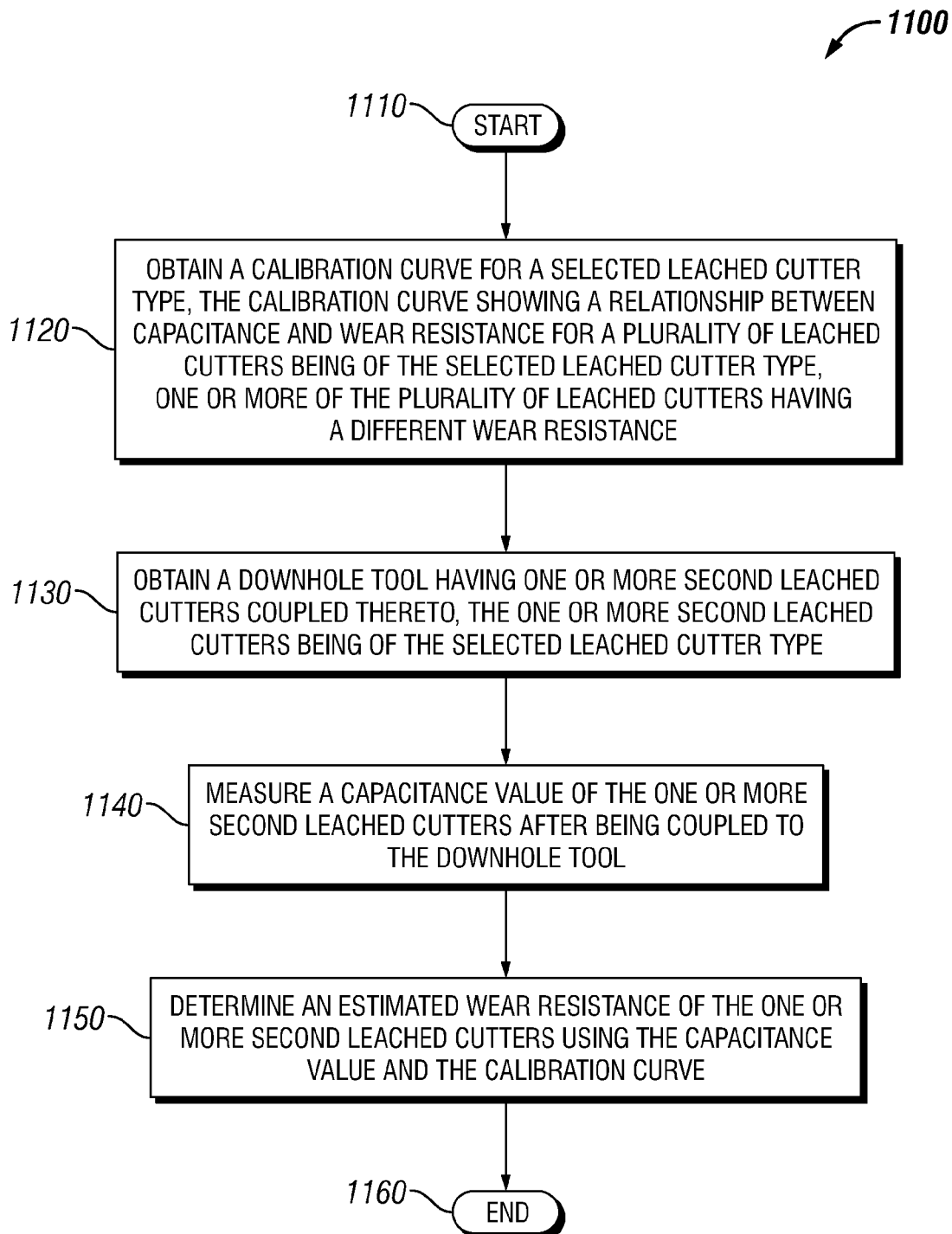


FIG. 10

**FIG. 11**

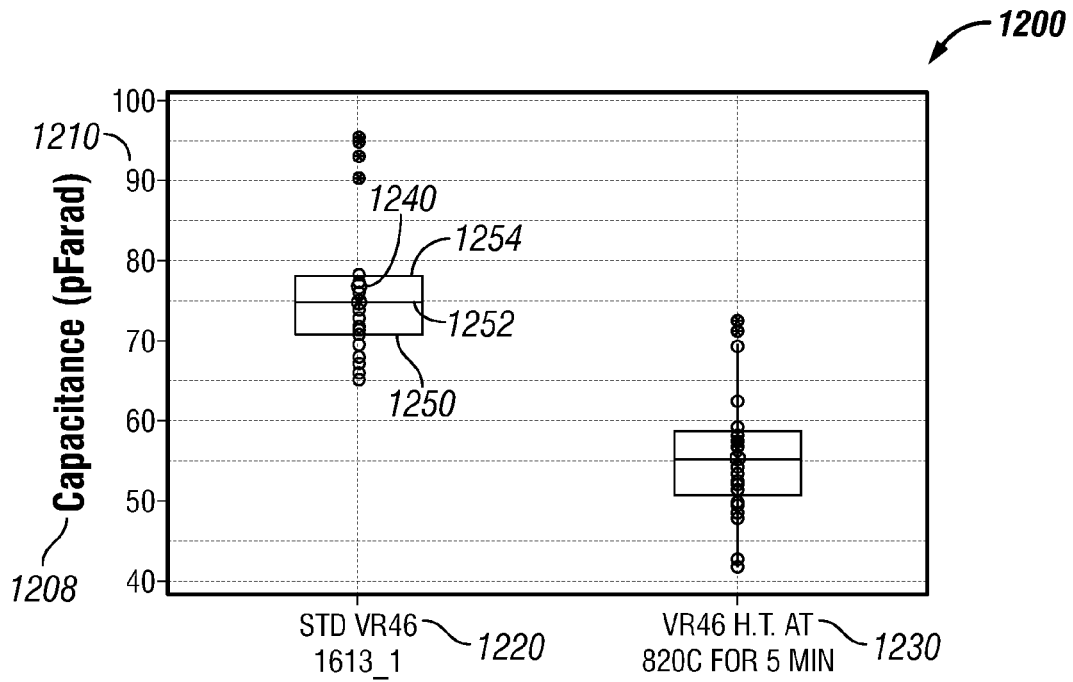


FIG. 12

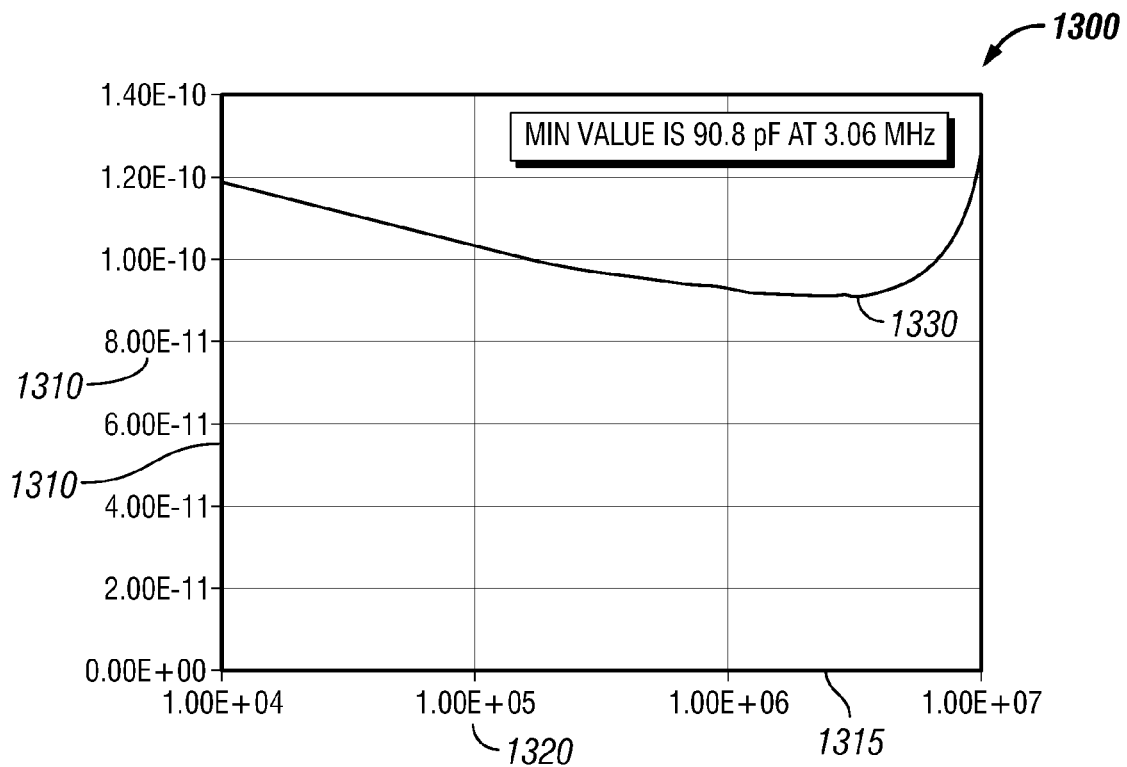


FIG. 13

METHOD AND APPARATUS TO ASSESS THE THERMAL DAMAGE CAUSED TO A PCD CUTTER USING CAPACITANCE SPECTROSCOPY

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation-in-part application of and claims priority under 35 U.S.C. §120 to U.S. patent application Ser. No. 13/401,188, titled "Use Of Capacitance To Analyze Polycrystalline Diamond," filed Feb. 21, 2012. The complete disclosure of the foregoing priority application is hereby fully incorporated by reference herein.

The present application is related to U.S. patent application Ser. No. 13/401,335, entitled "Use of Capacitance and Eddy Currents to Analyze Polycrystalline Diamond" and filed on Feb. 21, 2012, and U.S. patent application Ser. No. 13/401,452, entitled "Method To Improve The Performance Of A Leached Cutter" and filed on Feb. 21, 2012, which are all incorporated by reference herein.

TECHNICAL FIELD

The present invention relates generally to a method and apparatus for measuring characteristics of one or more regions within an ultra-hard polycrystalline structure; and more particularly, to a non-destructive method and apparatus for determining any thermal damage taken by a ultra-hard polycrystalline structure, such as the ones used in forming polycrystalline diamond compact ("PDC") cutters, that has been leached to a desired depth upon being exposed to high temperatures, such as the brazing process for coupling the PDC cutter to a drill bit or the like.

BACKGROUND

Polycrystalline diamond compacts ("PDC") have been used in industrial applications, including rock drilling applications and metal machining applications. Such compacts have demonstrated advantages over some other types of cutting elements, such as better wear resistance and impact resistance. The PDC can be formed by sintering individual diamond particles together under the high pressure and high temperature ("HPHT") conditions referred to as the "diamond stable region," which is typically above forty kilobars and between 1,200 degrees Celsius and 2,000 degrees Celsius, in the presence of a catalyst/solvent which promotes diamond-diamond bonding. Some examples of catalyst/solvents for sintered diamond compacts are cobalt, nickel, iron, and other Group VIII metals. PDCs usually have a diamond content greater than seventy percent by volume, with about eighty percent to about ninety-eight percent being typical. An unbacked PDC can be mechanically bonded to a tool (not shown), according to one example. Alternatively, the PDC is bonded to a substrate, thereby forming a PDC cutter, which is typically insertable within a downhole tool (not shown), such as a drill bit or a reamer.

FIG. 1 shows a side view of a PDC cutter 100 having a polycrystalline diamond ("PCD") cutting table 110, or compact, in accordance with the prior art. Although a PCD cutting table 110 is described in the exemplary embodiment, other types of cutting tables, including polycrystalline boron nitride ("PCBN") compacts, are used in alternative types of cutters. Referring to FIG. 1, the PDC cutter 100 typically includes the PCD cutting table 110 and a substrate 150 that is coupled to the PCD cutting table 110. The PCD cutting

table 110 is about one hundred thousandths of an inch (2.5 millimeters) thick; however, the thickness is variable depending upon the application in which the PCD cutting table 110 is to be used.

The substrate 150 includes a top surface 152, a bottom surface 154, and a substrate outer wall 156 that extends from the circumference of the top surface 152 to the circumference of the bottom surface 154. The PCD cutting table 110 includes a cutting surface 112, an opposing surface 114, and a PCD cutting table outer wall 116 that extends from the circumference of the cutting surface 112 to the circumference of the opposing surface 114. The opposing surface 114 of the PCD cutting table 110 is coupled to the top surface 152 of the substrate 150. Typically, the PCD cutting table 110 is coupled to the substrate 150 using a high pressure and high temperature ("HPHT") press. However, other methods known to people having ordinary skill in the art can be used to couple the PCD cutting table 110 to the substrate 150. In one embodiment, upon coupling the PCD cutting table 110 to the substrate 150, the cutting surface 112 of the PCD cutting table 110 is substantially parallel to the substrate's bottom surface 154. Additionally, the PDC cutter 100 has been illustrated as having a right circular cylindrical shape; however, the PDC cutter 100 is shaped into other geometric or non-geometric shapes in other exemplary embodiments. In certain exemplary embodiments, the opposing surface 114 and the top surface 152 are substantially planar; however, the opposing surface 114 and the top surface 152 are non-planar in other exemplary embodiments. Additionally, according to some exemplary embodiments, a bevel (not shown) is formed around at least the circumference of the cutting surface 112.

According to one example, the PDC cutter 100 is formed by independently forming the PCD cutting table 110 and the substrate 150, and thereafter bonding the PCD cutting table 110 to the substrate 150. Alternatively, the substrate 150 is initially formed and the PCD cutting table 110 is subsequently formed on the top surface 152 of the substrate 150 by placing polycrystalline diamond powder onto the top surface 152 and subjecting the polycrystalline diamond powder and the substrate 150 to a high temperature and high pressure process. Alternatively, the substrate 150 and the PCD cutting table 110 are formed and bonded together at about the same time. Although a few methods of forming the PDC cutter 100 have been briefly mentioned, other methods known to people having ordinary skill in the art can be used.

According to one example for forming the PDC cutter 100, the PCD cutting table 110 is formed and bonded to the substrate 150 by subjecting a layer of diamond powder and a mixture of tungsten carbide and cobalt powders to HPHT conditions. The cobalt is typically mixed with tungsten carbide and positioned where the substrate 150 is to be formed. The diamond powder is placed on top of the cobalt and tungsten carbide mixture and positioned where the PCD cutting table 110 is to be formed. The entire powder mixture is then subjected to HPHT conditions so that the cobalt melts and facilitates the cementing, or binding, of the tungsten carbide to form the substrate 150. The melted cobalt also diffuses, or infiltrates, into the diamond powder and acts as a catalyst for synthesizing diamond bonds and forming the PCD cutting table 110. Thus, the cobalt acts as both a binder for cementing the tungsten carbide and as a catalyst/solvent for sintering the diamond powder to form diamond-diamond bonds. The cobalt also facilitates in forming strong bonds between the PCD cutting table 110 and the cemented tungsten carbide substrate 150.

Cobalt has been a preferred constituent of the PDC manufacturing process. Traditional PDC manufacturing processes use cobalt as the binder material for forming the substrate **150** and also as the catalyst material for diamond synthesis because of the large body of knowledge related to using cobalt in these processes. The synergy between the large bodies of knowledge and the needs of the process have led to using cobalt as both the binder material and the catalyst material. However, as is known in the art, alternative metals, such as iron, nickel, chromium, manganese, and tantalum, and other suitable materials, can be used as a catalyst for diamond synthesis. When using these alternative materials as a catalyst for diamond synthesis to form the PCD cutting table **110**, cobalt, or some other material such as nickel chrome or iron, is typically used as the binder material for cementing the tungsten carbide to form the substrate **150**. Although some materials, such as tungsten carbide and cobalt, have been provided as examples, other materials known to people having ordinary skill in the art can be used to form the substrate **150**, the PCD cutting table **110**, and the bonds between the substrate **150** and the PCD cutting table **110**.

FIG. 2 is a schematic microstructural view of the PCD cutting table **110** of FIG. 1 in accordance with the prior art. Referring to FIGS. 1 and 2, the PCD cutting table **110** has diamond particles **210** bonded to other diamond particles **210**, one or more interstitial spaces **212** formed between the diamond particles **210**, and cobalt **214**, or some other catalyst, deposited within one or more of the interstitial spaces **212**. During the sintering process, the interstitial spaces **212**, or voids, are formed between the carbon-carbon bonds and are located between the diamond particles **210**. The diffusion of cobalt **214** into the diamond powder results in cobalt **214** being deposited within these interstitial spaces **212** that are formed within the PCD cutting table **110** during the sintering process.

Once the PCD cutting table **110** is formed and placed into operation, the PCD cutting table **110** is known to wear quickly when the temperature reaches a critical temperature. This critical temperature is about 750 degrees Celsius and is reached when the PCD cutting table **110** is cutting rock formations or other known materials. The high rate of wear is believed to be caused by the differences in the thermal expansion rate between the diamond particles **210** and the cobalt **214** and also by the chemical reaction, or graphitization, that occurs between cobalt **214** and the diamond particles **210**. The coefficient of thermal expansion for the diamond particles **210** is about 1.0×10^{-6} millimeters⁻¹ × Kelvin⁻¹ ("mm⁻¹K⁻¹"), while the coefficient of thermal expansion for the cobalt **214** is about 13.0×10^{-6} mm⁻¹K⁻¹. Thus, the cobalt **214** expands much faster than the diamond particles **210** at temperatures above this critical temperature, thereby making the bonds between the diamond particles **210** unstable. The PCD cutting table **110** becomes thermally degraded at temperatures above about 750 degrees Celsius and its cutting efficiency deteriorates significantly.

Efforts have been made to slow the wear of the PCD cutting table **110** at these high temperatures. These efforts include performing a leaching process on the PCD cutting table **110**, which removes some of the cobalt **214** from the interstitial spaces **212**. These leaching processes, which includes, but is not limited to, an acid leaching process and/or an electrolytic leaching process, is known to persons having ordinary skill in the art and is not described herein for the sake of brevity. By removing some of the cobalt **214**, or catalyst, from the PCD cutting table **110**, the thermal degradation of the PCD structure is reduced.

FIG. 3 shows a cross-section view of a leached PDC cutter **300** having a PCD cutting table **310** that has been at least partially leached in accordance with the prior art. Referring to FIG. 3, the PDC cutter **300** includes the PCD cutting table **310** coupled to a substrate **350**. The substrate **350** is similar to substrate **150** (FIG. 1) and is not described again for the sake of brevity. The PCD cutting table **310** is similar to the PCD cutting table **110** (FIG. 1), but includes a leached layer **354** and an unleached layer **356**. The leached layer **354** extends from the cutting surface **312**, which is similar to the cutting surface **112** (FIG. 1), towards an opposing surface **314**, which is similar to the opposing surface **114** (FIG. 1). In the leached layer **354**, at least a portion of the cobalt **214** has been removed from within the interstitial spaces **212** (FIG. 2) using at least one leaching process mentioned above. Thus, the leached layer **354** has been leached to a desired depth **353**. However, during the leaching process, one or more by-product materials **398** are formed and deposited within some of the interstitial spaces **212** (FIG. 2) in the leached layer **354**. These by-product materials **398** may be removed from the leached layer **354** in certain applications by methods known to people having ordinary skill in the art. The unleached layer **356** is similar to the PCD cutting table **150** (FIG. 1) and extends from the end of the leached layer **354** to the opposing surface **314**. In the unleached layer **356**, the cobalt **214** (FIG. 2) remains within the interstitial spaces **212** (FIG. 2). Although a boundary line **355** is formed between the leached layer **354** and the unleached layer **356** and is depicted as being substantially linear, the boundary line **355** can be non-linear.

The leached PDC cutters **300** are leached to different desired depths **353** and how deep the cutter **300** has been leached has an effect on the performance of the cutter **300**. Conventionally, the leached depth **353** of the cutter **300** is measured, or determined, by cutting the cutter **300** vertically in half and then subsequently polishing the cutter **300**. The leached depth **353** is visually measured under a microscope or similar magnifying device. This process is rather tedious and cumbersome as it involves cutting the cutter **300**, such as by electrical discharge machining ("EDM"), mounting, grinding, and polishing the cutter **300**, and performing an analysis under a microscope. Additionally, this process destroys the cutter **300** from subsequently being used. The leached depth **353** that is determined in this manner is assumed to be the same leached depth in other cutters that were leached in the same batch.

The leached PDC cutters **300** are typically brazed onto a drill bit head, or other downhole tool, by means of a blow torch. During this brazing process, the leached PDC cutters **300** can be damaged by the prolonged exposure to too high temperatures. The exposure to high heat for a prolonged time period can cause the catalyst to move around within the diamond table, thereby changing the leaching depth and affecting the performance of the cutters **300**. These damaged leached PDC cutters **300** will cause the bit to underperform in the field. At the moment, there is no current technology available to the bit manufacturer that allows quantifying, or objectively determining, the amount of thermal damage taken by the leached PDC cutter **300** during the brazing process in a non-destructive manner.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features and aspects of the invention are best understood with reference to the follow-

5

ing description of certain exemplary embodiments, when read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a side view of a PDC cutter having a polycrystalline diamond cutting table, or compact, in accordance with the prior art;

FIG. 2 is a schematic microstructural view of the PCD cutting table of FIG. 1 in accordance with the prior art;

FIG. 3 is a cross-section view of a PDC cutter having a PCD cutting table that has been at least partially leached in accordance with the prior art;

FIG. 4 is a schematic view of a capacitance measuring system in accordance to one exemplary embodiment of the present invention;

FIG. 5 is a schematic view of a capacitance measuring system in accordance to another exemplary embodiment of the present invention;

FIG. 6 is a flowchart depicting a non-destructive leaching depth estimation method in accordance with an exemplary embodiment of the present invention;

FIG. 7 is a graphical chart depicting a calibration curve that shows a relationship between capacitance and actual leaching depth for a plurality of leached components in accordance with an exemplary embodiment of the present invention;

FIG. 8 is a flowchart depicting a microstructural quality determination method in accordance with an exemplary embodiment of the present invention;

FIG. 9 is a data scattering chart that shows the measured capacitance for a plurality of cutters in accordance with an exemplary embodiment of the present invention;

FIG. 10 is a schematic view of a capacitance measuring system in accordance to yet another exemplary embodiment of the present invention;

FIG. 11 is a flowchart depicting a non-destructive wear resistance estimation method in accordance with an exemplary embodiment of the present invention;

FIG. 12 is a graphical chart showing a measured capacitance value of a leached cutter prior to being affected by a heat treatment and a second leached cutter that has been affected by a heat treatment in accordance with an exemplary embodiment of the present invention; and

FIG. 13 is a capacitance-to-frequency chart illustrating a relationship between a frequency value and a capacitance value in accordance with an exemplary embodiment of the present invention.

The drawings illustrate only exemplary embodiments of the invention and are therefore not to be considered limiting of its scope, as the invention may admit to other equally effective embodiments.

BRIEF DESCRIPTION OF EXEMPLARY EMBODIMENTS

The present invention is directed to a non-destructive method and apparatus for determining any thermal damage taken by an ultra-hard polycrystalline structure, such as the ones used in forming polycrystalline diamond compact ("PDC") cutters, that has been leached to a desired depth upon being exposed to high temperatures, such as the brazing process for coupling the PDC cutter to a drill bit or the like. Although the description of exemplary embodiments is provided below in conjunction with a PDC cutter, alternate embodiments of the invention may be applicable to other types of polycrystalline structures including, but not limited to, PCBN cutters. Further, according to some exemplary embodiments, one or more portions of the methods

6

described below is implemented using an electronic measuring device. For example, the capacitance is measured using a capacitance measuring device. The invention is better understood by reading the following description of non-limiting, exemplary embodiments with reference to the attached drawings, wherein like parts of each of the figures are identified by like reference characters, and which are briefly described as follows.

FIG. 4 is a schematic view of a capacitance measuring system 400 in accordance to one exemplary embodiment of the present invention. Referring to FIG. 4, the capacitance measuring system 400 includes a capacitance measuring device 410, the leached PDC cutter 300, a first wire 430, and a second wire 440. Although certain components have been enumerated as being included in the capacitance measuring system 400, additional components are included in other exemplary embodiments. Additionally, although the description provided below has been provided with respect to the leached PDC cutter 300, a different component, such as the PCD cutting table 310 alone or other component that includes another type of leached polycrystalline structure, is used in lieu of the leached PDC cutter 300. Additionally, although the description provided below has been provided with respect to the leached PDC cutter 300, a different component, such as a chemically cleaned leached PDC cutter (not shown), is used in lieu of the leached PDC cutter 300. The chemically cleaned leached PDC cutter has had at least a portion of the by-product materials 398 (FIG. 3) removed by using one or more processes described in related application entitled, "Method To Improve The Performance Of A Leached Cutter", which has been mentioned above and incorporated by reference herein. The leached PDC cutter 300 has been previously described with respect to FIG. 3 and is not repeated again herein for the sake of brevity.

The capacitance measuring device 410 is a device that measures the capacitance of an energy storage device, which is the leached PDC cutter 300 in the instant exemplary embodiment. Capacitance is a measure of the amount of electric potential energy stored, or separated, for a given electric potential. A common form of energy storage device is a parallel-plate capacitor. In the instant exemplary embodiment, the leached PDC cutter 300 is an example of the parallel-plate capacitor. The capacitance of the energy storage device is typically measured in farads, or nanofarads.

One example of the capacitance measuring device 410 is a multi-meter; however, other capacitance measuring devices known to people having ordinary skill in the art are used in one or more alternative exemplary embodiments. The multi-meter 410 includes a positionable dial 412, a plurality of measurement settings 414, a display 416, a positive terminal 418, and a negative terminal 419. According to some exemplary embodiments, the positionable dial 412 is rotatable in a clockwise and/or counter-clockwise manner and is set to one of several available measurement settings 414. In the instant exemplary embodiment, the positionable dial 412 is set to a nanofaraday setting 415 so that the multi-meter 410 measures capacitance values. The display 416 is fabricated using polycarbonate, glass, plastic, or other known suitable material and communicates a measurement value, such as a capacitance value, to a user (not shown) of the multi-meter 410. The positive terminal 418 is electrically coupled to one end of the first wire 430, while the negative terminal 419 is electrically coupled to one end of the second wire 440.

The first wire 430 is fabricated using a copper wire or some other suitable conducting material or alloy known to

people having ordinary skill in the art. According to some exemplary embodiments, the first wire **430** also includes a non-conducting sheath (not shown) that surrounds the copper wire and extends from about one end of the copper wire to an opposing end of the copper wire. The two ends of the copper wire are exposed and are not surrounded by the non-conducting sheath. In some exemplary embodiments, an insulating material (not shown) also surrounds the copper wire and is disposed between the copper wire and the non-conducting sheath. The insulating material extends from about one end of the non-conducting sheath to about an opposing end of the non-conducting sheath. As previously mentioned, one end of the first wire **430** is electrically coupled to the positive terminal **418**, while the opposing end of the first wire **430** is electrically coupled to the cutting surface **312** of the leached PDC cutter **300**. The opposing end of the first wire **430** is electrically coupled to the cutting surface **312** in one of several methods. In one example, the first wire **430** is electrically coupled to the cutting surface **312** using one or more fastening devices (not shown), such as a clamp, or using an equipment (not shown) that supplies a force to retain the first wire **430** in electrical contact with the cutting surface **312**. In another example, a clamp (not shown) is coupled to the opposing end of the first wire **430** and a conducting component (not shown), such as aluminum foil, is coupled to, or placed in contact with, the cutting surface **312**. The clamp is electrically coupled to the conducting component, thereby electrically coupling the first wire **430** to the cutting surface **312**. Additional methods for coupling the first wire **430** to the cutting surface **312** can be used in other exemplary embodiments.

The second wire **440** is fabricated using a copper wire or some other suitable conducting material or alloy known to people having ordinary skill in the art. According to some exemplary embodiments, the second wire **440** also includes a non-conducting sheath (not shown) that surrounds the copper wire and extends from about one end of the copper wire to an opposing end of the copper wire. The two ends of the copper wire are exposed and are not surrounded by the non-conducting sheath. In some exemplary embodiments, an insulating material (not shown) also surrounds the copper wire and is disposed between the copper wire and the non-conducting sheath. The insulating material extends from about one end of the non-conducting sheath to an opposing end of the non-conducting sheath. As previously mentioned, one end of the second wire **440** is electrically coupled to the negative terminal **419**, while the opposing end of the second wire **440** is electrically coupled to a bottom surface **454**, which is similar to the bottom surface **154** (FIG. 1), of the leached PDC cutter **300**. The second wire **440** is electrically coupled to the bottom surface **454** in a similar manner as the first wire **430** is electrically coupled to the cutting surface **312**.

Hence, a circuit **405** is completed using the multi-meter **410**, the first wire **430**, the leached PDC cutter **300**, and the second wire **440**. The current is able to flow from the positive terminal **418** of the multi-meter **410** to the cutting surface **312** of the leached PDC cutter **300** through the first wire **430**. The current then flows through the leached PDC cutter **300** to the bottom surface **454** of the leached PDC cutter **300**. When the multi-meter **410** is turned on, a voltage differential exists between the cutting surface **312** and the bottom surface **454**. The current then flows from the bottom surface **454** to the negative terminal **419** of the multi-meter **410** through the second wire **440**. The capacitance measurement of the leached PDC cutter **300** is determined when the

value displayed on the display **416** reaches a peak value or remains constant for a period of time.

FIG. 5 is a schematic view of a capacitance measuring system **500** in accordance to another exemplary embodiment of the present invention. Referring to FIG. 5, the capacitance measuring system **500** includes the capacitance measuring device **410**, the leached PDC cutter **300**, the first wire **430**, the second wire **440**, a first conducting material **510**, a second conducting material **520**, a first insulating material **530**, a second insulating material **540**, and an Arbor Press **550**. Although certain components have been enumerated as being included in the capacitance measuring system **500**, additional components are included in other exemplary embodiments. Further, although certain components have been enumerated as being included in the capacitance measuring system **500**, alternative components having similar functions as the enumerated components are used in alternative exemplary embodiments. Additionally, although the description provided below has been provided with respect to the leached PDC cutter **300**, a different component, such as the PCD cutting table **310** (FIG. 3) alone or other component that includes another type of leached polycrystalline structure, is used in lieu of the leached PDC cutter **300**. Additionally, although the description provided below has been provided with respect to the leached PDC cutter **300**, a different component, such as the chemically cleaned leached PDC cutter mentioned above, is used in lieu of the leached PDC cutter **300**. The capacitance measuring device **410**, the leached PDC cutter **300**, the first wire **430**, and the second wire **440** have been previously described and are not repeated again herein for the sake of brevity.

The first conducting material **510** and the second conducting material **520** are similar to one another in certain exemplary embodiments, but are different in other exemplary embodiments. According to one exemplary embodiment, the conducting materials **510**, **520** are fabricated using aluminum foil; however, other suitable conducting materials can be used. The first conducting material **510** is positioned adjacently above and in contact with the cutting surface **312**. The second conducting material **520** is positioned adjacently below and in contact with the bottom surface **454**. The first conducting material **510** and the second conducting material **520** provide an area to which the first wire **430** and the second wire **440**, respectively, make electrical contact. Additionally, the first conducting material **510** and the second conducting material **520** assist in minimizing contact resistance with the cutting surface **312** and the bottom surface **454**, respectively, which is discussed in further detail below. In certain exemplary embodiments, the first conducting material **510** and the second conducting material **520** are the same shape and size; while in other exemplary embodiments, one of the conducting materials **510**, **520** is a different shape and/or size than the other conducting material **510**, **520**.

The first insulating material **530** and the second insulating material **540** are similar to one another in certain exemplary embodiments, but are different in other exemplary embodiments. According to one exemplary embodiment, the insulating materials **530**, **540** are fabricated using paper; however, other suitable insulating materials, such as rubber, can be used. The first insulating material **530** is positioned adjacently above and in contact with the first conducting material **510**. The second insulating material **540** is positioned adjacently below and in contact with the second conducting material **520**. The first insulating material **530** and the second insulating material **540** provide a barrier to direct current flow only through a circuit **505**, which is

discussed in further detail below. In certain exemplary embodiments, the first insulating material **530** and the second insulating material **540** are the same shape and size; while in other exemplary embodiments, one of the insulating materials **530**, **540** is a different shape and/or size than the other insulating material **530**, **540**. Additionally, in certain exemplary embodiments, the insulating materials **530**, **540** is larger in size than its corresponding conducting material **510**, **520**. However, one or more of the insulating materials **530**, **540** is either larger or smaller than its corresponding conducting material **510**, **520** in alternative exemplary embodiments.

The Arbor Press **550** includes an upper plate **552** and a base plate **554**. The upper plate **552** is positioned above the base plate **554** and is movable towards the base plate **554**. In other exemplary embodiments, the base plate **554** is movable towards the upper plate **552**. The first insulating material **530**, the first conducting material **510**, the leached PDC cutter **300**, the second conducting material **520**, and the second insulating material **540** are positioned between the upper plate **552** and the base plate **554** such that the second insulating material **540** is positioned adjacently above and in contact with the base plate **554**. The upper plate **552** is moved towards the base plate **554** until the upper plate **552** applies a downward load **553** onto the cutting surface **312** of the leached PDC cutter **300**. When the downward load **553** is applied, the first conducting material **510** is deformed and adapted to the rough and very stiff cutting surface **312**, thereby minimizing contact resistance between the first conducting material **510** and the cutting surface **312** and greatly improving the capacitance measurement consistency. At this time, the base plate **554** also applies an upward load **555** onto the bottom surface **454** of the leached PDC cutter **300**. When the upward load **555** is applied, the second conducting material **520** is deformed and adapted to the rough and very stiff bottom surface **454**, thereby minimizing contact resistance between the second conducting material **520** and the bottom surface **454** and greatly improving the capacitance measurement consistency. In certain exemplary embodiments, the downward load **553** is equal to the upward load **555**. The downward load **553** and the upward load **555** is about one hundred pounds; however, these loads **553**, **555** range from about two pounds to about a critical load. The critical load is a load at which the leached PDC cutter **300** is damaged when applied thereto.

In one exemplary embodiment, the second insulating material **540** is positioned on the base plate **554**, the second conducting material **520** is positioned on the second insulating material **540**, the leached PDC cutter **300** is positioned on the second conducting material **520**, the first conducting material **510** is positioned on the leached PDC cutter **300**, and the first insulating material **530** is positioned on the first conducting material **510**. The upper plate **552** is moved towards the first insulating material **530** until the downward load **553** is applied onto the leached PDC cutter **300**. In an alternative exemplary embodiment, one or more components, such as the first insulating material **530** and the first conducting material **510**, are coupled to the upper plate **552** prior to the upper plate **552** being moved towards the base plate **554**. Although an Arbor Press **550** is used in the capacitance measuring system **500**, other equipment capable of delivering equal and opposite loads to each of the cutting surface **312** and the bottom surface **454** of the leached PDC cutter **300** can be used in other exemplary embodiments.

One end of the first wire **430** is electrically coupled to the positive terminal **418** of the multi-meter **410**, while the opposing end of the first wire **430** is electrically coupled to

the first conducting material **510**, which thereby becomes electrically coupled to the cutting surface **312** of the leached PDC cutter **300**. In one exemplary embodiment, a clamp **590** is coupled to the opposing end of the first wire **430** which couples the first wire **430** to the first conducting material **510**. One end of the second wire **440** is electrically coupled to the negative terminal **419** of the multi-meter **410**, while the opposing end of the second wire **440** is electrically coupled to the second conducting material **520**, which thereby becomes electrically coupled to the bottom surface **454** of the leached PDC cutter **300**. In one exemplary embodiment, a clamp (not shown), similar to clamp **590**, is coupled to the opposing end of the second wire **440**, which couples the second wire **440** to the second conducting material **520**. Hence, the circuit **505** is completed using the multi-meter **410**, the first wire **430**, the first conducting material **510**, the leached PDC cutter **300**, the second conducting material **520**, and the second wire **440**. The current is able to flow from the positive terminal **418** of the multi-meter **410** to the cutting surface **312** of the leached PDC cutter **300** through the first wire **430** and the first conducting material **510**. The current then flows through the leached PDC cutter **300** to the bottom surface **454** of the leached PDC cutter **300**. When the multi-meter **410** is turned on, a voltage differential exists between the cutting surface **312** and the bottom surface **454**. The current then flows from the bottom surface **454** to the negative terminal **419** of the multi-meter **410** through the second conducting material **520** and the second wire **440**. The first insulating material **530** and the second insulating material **540** prevent the current from flowing into the Arbor Press **550**. The capacitance measurement of the leached PDC cutter **300** is determined when the value displayed on the display **416** reaches a peak value or remains constant for a period of time.

FIG. 6 is a flowchart depicting a non-destructive leaching depth estimation method **600** in accordance with an exemplary embodiment of the present invention. Although FIG. 6 shows a series of steps depicted in a certain order, the order of one or more steps can be rearranged, combined into fewer steps, and/or separated into more steps than that shown in other exemplary embodiments. Referring to FIG. 6, the non-destructive leaching depth estimation method **600** begins at step **610**. Upon starting at step **610**, the non-destructive leaching depth estimation method **600** proceeds to step **620**. At step **620**, a calibration curve is obtained. The calibration curve can be generated from tests or acquired from elsewhere.

FIG. 7 is a graphical chart **700** depicting the calibration curve **705** that shows a relationship between capacitance **710** and actual leaching depth **720** for a plurality of leached components **300** (FIG. 3) in accordance with an exemplary embodiment of the present invention. Referring to FIG. 7, one or more of the leached components **300** (FIG. 3) have a different actual leaching depth **720** than at least one other leached component **300** (FIG. 3). The leached component **300** (FIG. 3) is the leached PDC cutter **300** (FIG. 3) according to some exemplary embodiments; however, the leached component **300** can be only the PCD cutting table **310** (FIG. 3) or some other component that has a polycrystalline structure that has had at least some of the catalyst material removed from therein. Alternatively, in certain exemplary embodiments, the leached component **300** can be the chemically cleaned leached PDC cutter mentioned above.

The calibration curve **705** is generated by obtaining two or more leached components **300** (FIG. 3). The calibration curve **705** becomes more precise as more leached compo-

11

nents 300 (FIG. 3) are used in generating the calibration curve 705. The capacitance data points 730 are obtained by measuring the capacitance 710 of each leached component 300 (FIG. 3). In certain exemplary embodiments, a plurality of capacitance data points 730 are obtained for each leached component 300 (FIG. 3). For example, the capacitance 710 is measured five times for each leached component 300 (FIG. 3). Obtaining a plurality of capacitance data points 730 for each leached component 300 (FIG. 3) improves the statistical significance of the capacitance data points 730 being collected. According to some exemplary embodiments, the leached component 300 (FIG. 3) is depolarized after each measurement for capacitance 710, before each measurement for capacitance 710, or before and after each measurement for capacitance 710. The leached component 300 is depolarized in one or a combination of different manners, such as grounding the leached component 300 (FIG. 3), wrapping the leached component 300 (FIG. 3) in aluminum foil or similar type material, heat treating the leached component 300 (FIG. 3), dropping the leached component 300 (FIG. 3) in a salt solution, or waiting to discharge the leached component 300 (FIG. 3). The leached component 300 (FIG. 3) is discharged by waiting about twenty-four hours, but the waiting time is greater or less in other exemplary embodiments. Depolarizing an object is known to people having ordinary skill in the art.

Once the capacitance 710 is measured for each leached component 300 (FIG. 3), the actual leaching depth 720 for each leached component 300 (FIG. 3) is determined. In some examples, the actual leaching depth 720 for a leached component 300 (FIG. 3) is determined by cutting the leached component 300 (FIG. 3), polishing the cut edge of the leached component 300 (FIG. 3), and visually measuring the actual leaching depth 720 under a magnifying device (not shown), such as a microscope. Although one method for determining the actual leaching depth 720 is described, other methods known to people having ordinary skill in the art can be used to determine the actual leaching depth 720 without departing from the scope and spirit of the exemplary embodiment. Each capacitance data point 730 is plotted on the graphical chart 700, where the actual leaching depth 720 is plotted versus the capacitance 710 that is measured. Once the capacitance data points 730 are plotted on the graphical chart 700, the calibration curve 705 is determined pursuant to methods known to people having ordinary skill in the art. For example, the calibration curve 705 is generated by using the average capacitance 711 of each leached component 300, the median capacitance 712 of each leached component, or by calculating the best fit curve. The best fit curve can be formed with a ninety-five percent confidence level, but this confidence level can range from about sixty percent to almost about one hundred percent, for example, 99.99 percent. The calibration curve 705 correlates the measured capacitance 710, which can be measured in nanofarads, with the actual leaching depth 720, which can be measured in microns. Although a few methods for generating the calibration curve 705 have been described, other methods, either destructive or non-destructive, can be used to generate the calibration curve 705.

According to FIG. 7, the actual leaching depth 720 is directly related to the capacitance 710. Thus, as the actual leaching depth 720 increases, the capacitance 710 that is measured also increases. Conversely, as the actual leaching depth 720 decreases, the capacitance 710 that is measured also decreases. Additionally, the data scattering, or range of measured capacitance 710, is greater as the actual leaching depth 720 increases. Although FIG. 7 shows a direct rela-

12

tionship between the actual leaching depth 720 and the capacitance 710; in actuality, the relationship between the capacitance 710 and the actual leaching depth 720 is an inverse relationship. The formula to calculate the capacitance 710 is:

$$C = \epsilon_r A / (4\pi d)$$

where

C is the capacitance;

A is the area of overlap of the two plates;

ϵ_r is the relative static permittivity (sometimes called the dielectric constant); and

d is the separation between the plates.

Thus, as "d", or the actual leaching depth 720, increases, the capacitance 710 decreases, and visa versa. The opposite phenomena is occurring in FIG. 7 because the by-product materials 398 (FIG. 3) present with the leached layer 354 (Figure) becomes polarized during the measurements, and thus the relative static permittivity is not constant.

Therefore, in certain exemplary embodiments, the leached layer 354 is treated, such as by chemical treatment, to have at least a portion of the by-product materials 398 (FIG. 3) removed. This treatment is dependent upon the methods and/or chemicals used to leach the PCD cutting table 310 (FIG. 3). This treated leached PDC cutter is used within the capacitance measuring system 400, 500 or within some other capacitance measuring system in lieu of the leached PDC cutter 300 (FIG. 3). The calibration curve that is determined using the treated leached PDC cutters would show the relationship between the actual leaching depth 720 and the capacitance 710 being an inverse relationship. In the methods using the treated leached PDC cutter, which has had at least a portion of the by-product materials 398 (FIG. 3) removed, the de-polarizing step is optional.

Referring back to FIG. 6, the non-destructive leaching depth estimation method 600 proceeds to step 630. At step 630, a similar type component, similar to leached cutter 300, is obtained. However, if the calibration curve was determined using treated leached PDC cutters, the similar type component is a different treated leached PDC cutter where the actual leaching depth is desired to be ascertained. This similar type component includes a polycrystalline structure that has a plurality of catalyst material therein. At least a portion of this catalyst material has been removed. This removed portion has an unknown depth, which is the leaching depth. The non-destructive leaching depth estimation method 600 proceeds to step 640. At step 640, the capacitance of the similar type component is measured. According to some exemplary embodiment, this capacitance is measured using the capacitance measuring system 400 (FIG. 4) or the capacitance measuring system 500 (FIG. 5). The non-destructive leaching depth estimation method 600 proceeds to step 650. At step 650, the estimated leaching depth of the similar type component is determined using the capacitance of the similar type component and the calibration curve 705 (FIG. 7). The estimated leaching depth is an estimation of the actual leaching depth and ranges from about one micron to about fifty microns from the actual leaching depth. The non-destructive leaching depth estimation method 600 proceeds to step 660, where the non-destructive leaching depth estimation method 600 ends.

FIG. 8 is a flowchart depicting a microstructural quality determination method 800 in accordance with an exemplary embodiment of the present invention. Although FIG. 8 shows a series of steps depicted in a certain order, the order of one or more steps can be rearranged, combined into fewer steps, and/or separated into more steps than that shown in

other exemplary embodiments. Referring to FIG. 8, the microstructural quality determination method **800** begins at step **810**. Upon starting at step **810**, the microstructural quality determination method **800** proceeds to step **820**. At step **820**, one or more leached components that include a polycrystalline structure is obtained from a same leached batch. The same leached batch is a group of components that were leached in the same leaching process at the same time. The polycrystalline structure includes a leached layer and a non-leached layer being positioned adjacently below the leached layer. The non-leached layer includes a plurality of catalyst material therein, while the leached layer has had at least a portion of the catalyst material removed. The microstructural quality determination method **800** proceeds to step **830**. At step **830**, a plurality of capacitance values are measured for each of the leached components. The capacitance values are determined using the capacitance measuring system **400** (FIG. 4) or the capacitance measuring system **500** (FIG. 5). The microstructural quality determination method **800** proceeds to step **840**. At step **840**, an amount of data scattering is determined for each leached component. The amount of data scattering for a leached component is determined by a differential between the highest measured capacitance and the lowest measured capacitance for that leached component and by statistical results of where each measured capacitance lies. The microstructural quality determination method **800** proceeds to step **850**. At step **850**, a quality of the leached component is determined based upon the amount of data scattering. The quality of the leached component relates to the microstructural quality and/or the leaching quality. The microstructural quality relates to the porosity of the microstructure. The microstructural quality is a good quality when there is low porosity. Conversely, the microstructural quality is a poor quality when there is high porosity. The leaching quality is a good quality when there is less catalyst materials present within the leached layer of the polycrystalline structure. Conversely, the leaching quality is a poor quality when there is more catalyst materials present within the leached layer of the polycrystalline structure. In some exemplary embodiments, the quality of the leached component is considered to be good when the amount of data scattering is determined to be small. Conversely, the quality of the leached component is considered to be poor when the amount of data scattering is determined to be large. The relative terms of small and large are determined when comparing the data scattering of a first leached component to the data scattering of a second leached component that was leached in the same batch as the first leached component.

FIG. 9 is a data scattering chart **900** that shows the measured capacitance **710** for a plurality of leached cutters **922** from a same leaching batch in accordance with an exemplary embodiment of the present invention. Referring to FIG. 9, the data scattering chart **900** includes a cutter number axis **920** and a capacitance axis **910**. The cutter number axis **920** includes the number of the cutters **922** tested. The capacitance axis **910** includes values for the measured capacitance **710**. A capacitance data point **930** is obtained by measuring the capacitance of the cutter **922**, or leached component **922**, using the capacitance measuring system **400** (FIG. 4), the capacitance measuring system **500** (FIG. 5), or a similar type system. Each capacitance data point **930** is plotted on the data scattering chart **900**. Each leached component **922** has its capacitance measured a plurality of times. In some exemplary embodiments, five capacitance data points **930** are obtained for each leached component **922**, however, the number of measurements is

greater or fewer in other exemplary embodiments. In some exemplary embodiments, a twenty-five percentile marking **950**, a fifty percentile marking **952** (or average), and a seventy-five percentile marking **954** is shown in the chart **900** for each leached component **922**. The area between the twenty-five percentile marking **950** and the seventy-five percentile marking **954** is shaded. The amount of data scattering is ascertained using this data scattering chart **900** and can be one or more of a differential between the highest and lowest capacitance measurements **710** for each leached component **922**, a range between the twenty-five percentile marking **950** and the seventy-five percentile marking **954**, or some similar observation made from the data scattering chart **900**.

According to FIG. 9, cutter number **4 923** and cutter number **9 924** have a larger data scattering than for example cutter number **6 925** or cutter number **7 926**. Hence, cutter number **4 923** and cutter number **9 924** have a poor leaching quality and/or a poor microstructural quality within the polycrystalline structure. The increase in amount of catalyst material within the polycrystalline structure causes this data scattering.

There are several benefits for non-destructively determining the leaching depth in an ultra-hard polycrystalline structure and/or characterizing at least a portion of the ultra-hard polycrystalline structure. For example, capacitance measurements can be made on all PDC cutters that are to be mounted and used in a tool, such as a drill bit or other downhole tool. In another example, when a quantity of PDC cutters being leached within the same leaching batch are provided, such as one thousand PDC cutters, the capacitance of the PDC cutters are measured pursuant to the descriptions provided above. The PDC cutters that meet a desired quality and/or leaching depth are kept while the remaining PDC cutters that do not meet the desired leaching depth and/or quality are returned. Thus, in one exemplary embodiment, although one thousand PDC cutters being leached from the same batch are provided, two hundred PDC cutters, or twenty percent, may be retained while the remaining are returned. Thus, only the higher quality and/or the proper leaching depth PDC cutters are paid for and retained, which results in the PDC cutters performing better during their application.

FIG. 10 is a schematic view of a capacitance measuring system **1000** in accordance to yet another exemplary embodiment of the present invention. Referring to FIG. 10, the capacitance measuring system **1000** includes the capacitance measuring device **410**, a drill bit **1010** having at least one leached PDC cutter **300** coupled thereto, the first wire **430**, and the second wire **440**. Further, according to certain exemplary embodiments, the capacitance measuring system **1000** also includes a first conductive component **1060** and a second conductive component **1070**. Although the drill bit **1010** has been enumerated as being part of the capacitance measuring system **1000**, any tool, for example, a downhole tool, having at least one leached PDC cutter **300** is part of the capacitance measuring system **1000** in lieu of the drill bit **1010**. Although certain components have been enumerated as being included in the capacitance measuring system **1000**, additional components are included in other exemplary embodiments. Additionally, although the description pro-

15

vided below has been provided with respect to the leached PDC cutter **300**, a different component, such as the PCD cutting table **310** (FIG. 3) alone or other component that includes another type of leached polycrystalline structure, is used in lieu of the leached PDC cutter **300**. Additionally, although the description provided below has been provided with respect to the leached PDC cutter **300**, a different component, such as a chemically cleaned leached PDC cutter (not shown), is used in lieu of the leached PDC cutter **300**. The chemically cleaned leached PDC cutter has had at least a portion of the by-product materials **398** (FIG. 3) removed by using one or more processes described in a related application entitled, "Method To Improve The Performance Of A Leached Cutter", which has been mentioned above and incorporated by reference herein. The capacitance measuring device **410**, the first wire **430**, the second wire **440**, and the leached PDC cutter **300** have been previously described with respect to FIGS. 3 and 4 and are therefore not repeated again in detail herein for the sake of brevity.

The drill bit **1010** includes a bit body **1005** that is coupled to a shank **1015** and is designed to rotate in a counter-clockwise direction **1090**. The drill bit **1010** is fabricated using matrix material, machined steel, or any other suitable material or combination of materials that are known to people having ordinary skill in the art. The shank **1015** includes a threaded connection **1016** at one end **1020**. The threaded connection **1016** couples to a drill string (not shown) or some other equipment that is coupled to the drill string. The threaded connection **1016** is shown to be positioned on the exterior surface of the one end **1020**. This positioning assumes that the drill bit **1010** is coupled to a corresponding threaded connection located on the interior surface of a drill string (not shown). However, the threaded connection **1016** at the one end **1020** is alternatively positioned on the interior surface of the one end **1020** if the corresponding threaded connection of the drill string (not shown) is positioned on its exterior surface in other exemplary embodiments. A bore (not shown) is formed longitudinally through the shank **1015** and a plenum (not shown) is formed within the bit body **1005**. The bore communicates drilling fluid from within the drill string to the plenum, which then communicates the drilling fluid to a drill bit face **1011**, on the exterior surface of the drill bit **1010**, via one or more nozzles **1014** during drilling operations. A flowpath (not shown) is formed within the bit body **1005** and extends from the plenum to the nozzle **1014**. Typically, the flowpaths are formed via machining and/or using displacements that are known to people having ordinary skill in the art.

The bit body **1005** includes a plurality of gauge sections **1050**, according to certain exemplary embodiments, and a plurality of blades **1030** extending from the drill bit face **1011** of the bit body **1005** towards the threaded connection **1016**, where each blade **1030** extends to and terminates at a respective gauge section **1050**. The blade **1030** and the respective gauge section **1050** are formed as a single component, but are formed separately in certain drill bits **1010**. The drill bit face **1011** is positioned at one end of the bit body **1005** furthest away from the shank **1015**. The plurality of blades **1030** form the cutting surface of the drill bit **1010**. One or more of these plurality of blades **1030** are either coupled to the bit body **1005** or are integrally formed with the bit body **1005**. The gauge sections **1050** are positioned at an end of the bit body **1005** adjacent the shank **1015**. The gauge section **1050** includes one or more gauge cutters (not shown) in certain drill bits **1010**. The gauge sections **1050** typically define and hold the full hole diameter of the drilled hole.

16

Each of the blades **1030** and gauge sections **1050** include a leading edge section **1032**, a face section **1034**, a trailing edge section **1036**, and an inner section **1038**. The face section **1034** extends from one longitudinal end of the trailing edge section **1036** to a longitudinal end of the leading edge section **1032**. The leading edge section **1032** faces in the direction of rotation **1090**, while the trailing edge section **1036** faces oppositely from the direction of rotation **1090**. The inner section **1038** extends from one latitudinal end of the trailing edge section **1036** to a latitudinal end of the leading edge section **1032** and from the drill bit face **1011** to an end of the face section **1034**. A junk slot **1022** is formed between each consecutive blade **1030**, which allows for cuttings and drilling fluid to return to the surface of the wellbore (not shown) once the drilling fluid is discharged from the nozzles **1014**. Each blade **1030** also includes one or more cutter pockets **1031** configured to receive a corresponding cutter **300**, where at least one of the cutters **300** is a leached PDC cutter **300**.

A plurality of cutters **300**, where at least one of the cutters **300** is a leached PDC cutter **300**, are coupled to each of the blades **1030** and extend outwardly from the surface of the blades **1030** to cut through earth formations when the drill bit **1010** is rotated during drilling. Although a leached PDC cutter **300** is used as one of the cutters **300**, other types of cutters having a leached polycrystalline structure are contemplated as being used within the drill bit **1010**. The cutters **300** and portions of the bit body **1005** deform the earth formation by scraping and/or shearing depending upon the type of drill bit **1010**. Although one embodiment of the drill bit has been described, other configurations of drill bit embodiments or other downhole tools, which are known to people having ordinary skill in the art, are applicable to exemplary embodiments of the present invention. The cutters **300** are coupled to the drill bit **3010** via a brazing technique or some other known technique. During this coupling process, the leached PDC cutters **300** may have properties altered due to being exposed to high temperatures for a certain time period. Changing of the depth **353** (FIG. 3) of the leached layer **354** (FIG. 3) during the coupling process affects the properties of the leached PDC cutter **300**.

The capacitance measuring device **410** includes the positionable dial **412**, a plurality of measurement settings **414**, the display **416**, the positive terminal **418**, and the negative terminal **419** according to certain exemplary embodiments. The positionable dial **412** is positioned to the nanofaraday setting **415** so that the capacitance measuring device **410**, or multi-meter **410**, measures capacitance values. These components have been previously been described and therefore are not repeated again herein for the sake of brevity. According to certain exemplary embodiments, the capacitance measuring device **410** includes a variable testing frequency that allows for capacitance measurements at different test frequencies. A second dial (not shown) or switch (not shown) may be included within the capacitance measuring device **410** to select the test frequency. According to some exemplary embodiments, the test frequency is variable from 100 kHz to 10 MHz, however, this frequency range is larger or smaller depending upon the testing requirements.

The first conductive component **1060** is coupled to the cutting surface **312** of the leached PDC cutter **300**. According to some exemplary embodiments, the first conductive component **1060** includes a conductive portion **1062** that is in contact with the cutting surface **312**. The surface of the conductive portion **1062** in contact with the cutting surface **312** is substantially planar according to some exemplary embodiments. According to some exemplary embodiments,

17

the first conductive component **1060** includes an insulator **1064** surrounding the circumference, or perimeter, of the conductive portion **1062**. In these exemplary embodiments, the insulator **1064** serves to reduce short circuiting when capacitance measurements are made on the leached PDC cutter **300** that has already been coupled to the drill bit **1010**. In some exemplary embodiments, the first conductive component **1060** is cylindrically shaped and has a circular profile, however the profile may be of other geometric or non-geometric shapes. Yet, in other exemplary embodiments, the first conductive component **1060** is annularly shaped and optionally includes an insulator **1064** along the interior circumference, or perimeter, as well as along the exterior circumference, or perimeter. In yet other exemplary embodiments, the first conductive component **1060** is a tape or foil that is fabricated using a conductive material, such as copper, aluminum, some other metal or metal alloy. A pressure may be applied onto the first conductive component **1060** so that the contact with the cutting surface **312** is maintained and constant during the capacitance measurement.

The second conductive component **1070** is coupled to the blade **1030** of the drill bit **1010** and is positioned adjacent the leached PDC cutter **300** that is being tested according to some exemplary embodiments. According to other exemplary embodiments, the second conductive component **1070** is positioned elsewhere along the drill bit **1010**. According to some exemplary embodiments, the second conductive component **1070** is a tape or foil that is fabricated using a conductive material, such as copper, aluminum, some other metal or metal alloy. A pressure may be applied onto the second conductive component **1070** so that the contact with the drill bit **1010** is maintained and constant during the capacitance measurement. In yet other exemplary embodiments, the second conductive component **1070** is similar to any of the other embodiments described with respect to the first conductive component **1060**. According to some exemplary embodiments, the first and second conductive components **1060**, **1070** are the same, while in other exemplary embodiments, the first and second conductive components **1060**, **1070** are different from one another. In other exemplary embodiments, any conductive component may be used as the second conductive component **1070**.

The first wire **430** has been previously described and therefore is not described again in detail for the sake of brevity. One end of the first wire **430** is electrically coupled to the positive terminal **418**, while the opposing end of the first wire **430** is electrically coupled to the cutting surface **312** of the leached PDC cutter **300** via the first conductive component **1060**. The opposing end of the first wire **430** is electrically coupled to the conductive portion **1062** of the first conductive component **1060** in one of several methods. In one example, the first wire **430** is electrically coupled to the conductive portion **1062** using one or more fastening devices (not shown), such as a clamp, or using an equipment that supplies a force to retain the first wire **430** in electrical contact with the conductive portion **1062**. The clamp is electrically coupled to the conductive portion **1062**, thereby electrically coupling the first wire **430** to the cutting surface **312**. Additional methods for coupling the first wire **430** to the conductive portion **1062** that are known to people having ordinary skill in the art can be used in other exemplary embodiments.

The second wire **440** has been previously described and therefore is not described again in detail for the sake of brevity. One end of the second wire **440** is electrically coupled to the negative terminal **419**, while the opposing end

18

of the second wire **440** is electrically coupled to the second conductive component **1070**. The second wire **440** is electrically coupled to the second conductive component **1070** in a similar manner as the first wire **430** is electrically coupled to the conductive portion **1062**. Additional methods for coupling the second wire **440** to the second conductive component **1070** that are known to people having ordinary skill in the art can be used in other exemplary embodiments.

Hence, a circuit **1002** is completed using the capacitance measuring device **410**, the first wire **430**, the leached PDC cutter **300** that is coupled to the drill bit **1010**, the drill bit **1010**, and the second wire **440**. The current is able to flow from the positive terminal **418** of the capacitance measuring device **410** to the cutting surface **312** of the leached PDC cutter **300** through the first wire **430** and the first conductive component **1060**. The current then flows through the leached PDC cutter **300** to the blade **1030**, or bit body **1005**, and into the second conductive component **1070**. When the capacitance measuring device **410** is turned on, a voltage differential exists between the cutting surface **312** and the blade **1030**, or bit body **1005**. The current then flows from the blade **1030**, or bit body **1005**, to the negative terminal **419** of the capacitance measuring device **410** through the second wire **440**. The capacitance measurement of the leached PDC cutter **300** is determined when the value displayed on the display **416** reaches a low peak value as the frequency is varied. Obtaining data when varying the frequency, or performing impedance spectroscopy or frequency sweeping, reduces noise in the measurement data.

FIG. **11** is a flowchart depicting a non-destructive wear resistance estimation method **1100** in accordance with an exemplary embodiment of the present invention. Although FIG. **11** shows a series of steps depicted in a certain order, the order of one or more steps can be rearranged, combined into fewer steps, and/or separated into more steps than that shown in other exemplary embodiments. Referring to FIG. **11**, the non-destructive wear resistance estimation method **1100** begins at step **1110**. Upon starting at step **1110**, the non-destructive wear resistance estimation method **1100** proceeds to step **1120**. At step **1120**, a calibration curve is obtained. The calibration curve can be generated from tests or acquired from elsewhere. The calibration curve is for a selected leached cutter type and shows a relationship between capacitance and wear resistance for a plurality of leached cutters being of the selected leached cutter type. One or more of the plurality of leached cutters have a different wear resistance, and thus a different capacitance measurement.

Although not illustrated, the calibration curve used in the non-destructive wear resistance estimation method **1100** is similar to the graphical chart **700** (FIG. **7**) that depicts the calibration curve **705** (FIG. **7**) which shows the relationship between capacitance **710** (FIG. **7**) and actual leaching depth **720** (FIG. **7**) for a plurality of leached components **300** (FIG. **3**), except that this calibration curve shows the relationship of capacitance with wear resistance instead of actual leaching depth **720** (FIG. **7**).

The calibration curve is generated by obtaining two or more leached components **300** (FIG. **3**) of the same cutter type. The calibration curve becomes more precise as more leached components **300** (FIG. **3**) are used in generating the calibration curve. The capacitance data points are obtained by measuring the capacitance **710** of each leached component **300** (FIG. **3**). The method for determining the capacitance is described in more detail in conjunction with the description provided for FIG. **13** below. In certain exemplary embodiments, a plurality of capacitance data points, or

19

measurements, are obtained for each leached component 300 (FIG. 3). For example, the capacitance is measured five times for each leached component 300 (FIG. 3). Obtaining a plurality of capacitance data points for each leached component 300 (FIG. 3) improves the statistical significance of the capacitance data points being collected. According to some exemplary embodiments, the leached component 300 (FIG. 3) is depolarized after each measurement for capacitance, before each measurement for capacitance, or before and after each measurement for capacitance. The leached component 300 is depolarized in one or a combination of different manners, such as grounding the leached component 300 (FIG. 3), wrapping the leached component 300 (FIG. 3) in aluminum foil or similar type material, heat treating the leached component 300 (FIG. 3), dropping the leached component 300 (FIG. 3) in a salt solution, or waiting to discharge the leached component 300 (FIG. 3). The leached component 300 (FIG. 3) is discharged by waiting about twenty-four hours, but the waiting time is greater or less in other exemplary embodiments. Depolarizing an object is known to people having ordinary skill in the art.

Once the capacitance is measured for each leached component 300 (FIG. 3), the wear resistance for each leached component 300 (FIG. 3) is determined. In some examples, the wear resistance for each of the leached components 300 (FIG. 3) is determined by using a VTL test, a granite log test, or any other test known to people having ordinary skill in the art. Each capacitance data point is plotted on a graphical chart (not shown), where the wear resistance is plotted versus the capacitance that is measured. Once the capacitance data points and the corresponding wear resistance data points are plotted on the graphical chart for each leached cutter 300 (FIG. 3), the calibration curve is determined pursuant to methods known to people having ordinary skill in the art. For example, the calibration curve is generated by using the average capacitance of each leached component 300 (FIG. 3), the median capacitance of each leached component 300 (FIG. 3), or by calculating the best fit curve. The best fit curve can be formed with a ninety-five percent confidence level, but this confidence level can range from about sixty percent to almost about one hundred percent, for example, 99.99 percent. The calibration curve correlates the measured capacitance, which can be measured in nanofarads, with the wear resistance. Although a few methods for generating the calibration curve have been described, other methods, either destructive or non-destructive, can be used to generate the calibration curve.

Continuing reference to FIG. 11, the non-destructive wear resistance estimation method 1100 proceeds to step 1130. At step 1130, a downhole tool having one or more second leached cutters coupled thereto is obtained. The one or more second leached cutters are similar to the selected leached cutter type used in generating the calibration curve of step 1120, except that they have been coupled to the downhole tool, such as by a brazing process. It is these one or more second leached cutters where the wear resistance is desired to be ascertained. The non-destructive wear resistance estimation method 1100 proceeds to step 1140. At step 1140, the capacitance value of the one or more second leached cutters are measured. As previously mentioned, these second leached cutters have already been coupled to the downhole tool, such as by a brazing process. According to some exemplary embodiment, this capacitance value is measured using the capacitance measuring system 1000 (FIG. 10). One example of how the capacitance of a cutter has been

20

estimation method 1110 proceeds to step 1150. At step 1150, the estimated wear resistance of the one or more second leached cutters is determined using the capacitance value of the one or more second leached cutters and the calibration curve obtained in step 1110. The estimated wear resistance is an estimation of the actual wear resistance of the one or more second leached cutters. The non-destructive wear resistance estimation method 1100 proceeds to step 1160, where the non-destructive wear resistance estimation method 1100 ends.

FIG. 12 is a graphical chart 1200 showing a measured capacitance value 1210 of a leached cutter 1220 without any heat treatment and a second leached cutter 1230 that has been affected by a heat treatment in accordance with an exemplary embodiment of the present invention. Referring to FIG. 12, the graphical chart 1200 includes a cutter type heat treatment axis 1215 and a capacitance axis 1208. The cutter type heat treatment axis 1215 includes the leached cutter 1220 and the second leached cutter 1230. The leached cutter 1220 is similar to the leached cutter 300 (FIG. 3) and has not been treated with any heat treatments, while the second leached cutter 1230 has been affected with a heat treatment. According to the example provided, the heat treatment affecting the second leached cutter 1230 is exposure of the second leached cutter 1230 at 820° C. for five minutes. This heat treatment is an example of the heat exposure that a cutter may be exposed during a brazing process, which is used to couple the cutter onto a downhole tool. Although only on second leached cutter 1230 is shown being exposed to a certain heat treatment, additional second leached cutters 1230 being exposed to a different temperature and/or for a different amount of time can be illustrated in the graphical chart 1200. For example, the temperature exposure can range from 750° C. to 850° C. for a time range from one minute to twenty minutes. However, the exposed temperature may be greater than 850° C. according to certain exemplary embodiments and the time range can be greater or less than the range provided according to certain exemplary embodiments, which may be dependent upon the cutter type used and/or the brazing material used and/or the material used to fabricate the downhole tool. The capacitance axis 1208 includes values for the measured capacitance 1210. A capacitance data point 1240 is obtained by measuring the capacitance of the cutter 1220, 1230, or leached component 1220, 1230, using the capacitance measuring system 400 (FIG. 4), the capacitance measuring system 500 (FIG. 5), capacitance measuring system 1000 (FIG. 10) or a similar type system and is determined according to the description provided with respect to FIG. 13. Each capacitance data point 1240 is plotted on the data scattering chart 1200. Each leached component 1220, 1230 has its capacitance measured a plurality of times. In some exemplary embodiments, five capacitance data points 1240 are obtained for each leached component 1220, 230, however, the number of measurements is greater or fewer in other exemplary embodiments. In some exemplary embodiments, a twenty-five percentile marking 1250, a fifty percentile marking 1252 (or average), and a seventy-five percentile marking 1254 is shown in the chart 1200 for each leached component 1220, 1230. The area between the twenty-five percentile marking 1250 and the seventy-five percentile marking 1254 is shaded. The amount of data scattering is ascertained using this data scattering chart 1200 and can be one or more of a differential between the highest and lowest capacitance measurements 1210 for each leached component 1220, 1230, a range between the twenty-five

21

percentile marking **1250** and the seventy-five percentile marking **1254**, or some similar observation made from the data scattering chart **1200**.

According to FIG. **12**, the leached cutter **1220** is a standard vr46 cutter that has not underwent any heat exposure, while the second leached cutter **1230** also is a standard vr46 cutter, but has underwent heat exposure at 820° C. for five minutes. According to the capacitance measurements, the second leached cutter **1220** has a lower capacitance measurement than the leached cutter **1220**. In particular, the second leached cutter **1230** has a capacitance measurement of about 51 pFarads to about 58 pFarads from the twenty-five percentile marking **1250** to the seventy-five percentile marking **1254**, respectively. However, the leached cutter **1220** has a capacitance measurement of about 71 pFarads to about 78 pFarads from the twenty-five percentile marking **1250** to the seventy-five percentile marking **1254**, respectively. Hence, the graphical chart **1200** shows that the capacitance of a cutter decreases upon being exposed to a heat treatment.

FIG. **13** is a capacitance-to-frequency chart **1300** illustrating a relationship between a capacitance value **1310** and a frequency value **1320** in accordance with an exemplary embodiment of the present invention. Referring to FIG. **13**, the capacitance-to-frequency chart **1300** includes a capacitance axis **1308** and a frequency axis **1315**. The capacitance **1310** is measured on a leached cutter **300**, **1220**, **1230** (FIGS. **10** and **12**) using impedance spectroscopy in accordance with an exemplary embodiment, which is by frequency sweeping or changing the frequency while measuring capacitance. Accordingly, a capacitance minimum value **1330** is obtained, as shown in the capacitance-to-frequency chart **1300**. This capacitance minimum value **1330** is the capacitance value **1210** (FIG. **12**) that is used in determining and/or facilitating the determination of the estimated wear resistance of the leached cutter. According to the capacitance-to-frequency chart **1300**, the capacitance minimum value **1330** is 90.8 pFarads, which occurs at a frequency value **1320** of 3.06 megahertz; however, these values can differ in other measurements made with different leached cutters.

Although each exemplary embodiment has been described in detail, it is to be construed that any features and modifications that are applicable to one embodiment are also applicable to the other embodiments. Furthermore, although the invention has been described with reference to specific embodiments, these descriptions are not meant to be construed in a limiting sense. Various modifications of the disclosed embodiments, as well as alternative embodiments of the invention will become apparent to persons of ordinary skill in the art upon reference to the description of the exemplary embodiments. It should be appreciated by those of ordinary skill in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other structures or methods for carrying out the same purposes of the invention. It should also be realized by those of ordinary skill in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims. It is therefore, contemplated that the claims will cover any such modifications or embodiments that fall within the scope of the invention.

22

What is claimed is:

1. A method of determining wear resistance of a downhole tool, comprising:

measuring capacitance values of a first plurality of leached polycrystalline diamond compact (PDC) cutters;

destructively testing wear resistance of each cutter of the first plurality to obtain calibration data;

brazing a second plurality of leached PDC cutters to the downhole tool, the first plurality and the second plurality being of the same type;

after brazing, measuring a capacitance value of each cutter of the second plurality; and

determining an estimated wear resistance of each cutter of the second plurality using the respective measured capacitance value of each cutter of the second plurality and the calibration data,

wherein:

multiple capacitance values are measured for each cutter of the second plurality at different frequencies, the method further comprises selecting a minimum capacitance value for each cutter of the second plurality, and

the minimum value is used to determine the estimated wear resistance of each cutter of the second plurality.

2. The method of claim 1, wherein the capacitance value of each cutter of the second plurality is measured by:

obtaining a capacitance measuring device comprising a positive terminal and a negative terminal;

electrically coupling a first wire from the positive terminal to a leached layer of the respective cutter; and

electrically coupling a second wire from the negative terminal to a surface of the downhole tool.

3. The method of claim 2, wherein the first wire is electrically coupled by positioning a first conducting component adjacent to and in contact with the leached layer of the respective cutter and the first wire.

4. The method of claim 3, wherein the first conducting component is cylindrically shaped or annularly shaped.

5. The method of claim 3, wherein the first conducting component is fabricated at least from a copper or copper alloy.

6. The method of claim 3, wherein the first conducting component comprises a conducting material and an insulating material, the insulating material surrounding at least a portion of the perimeter of the conducting material.

7. The method of claim 2, wherein the second wire is electrically coupled by positioning a second conducting component adjacent to and in contact with the surface of the downhole tool and the second wire.

8. The method of claim 7, wherein the second conducting component comprises a foil.

9. The method of claim 7, wherein the second conducting component is fabricated at least from a copper or copper alloy.

10. The method of claim 1, wherein the wear resistance of each cutter of the first plurality is measured using a vertical turret lathe (VTL) test or a granite log test.

11. A method of determining wear resistance of a downhole tool, comprising:

measuring capacitance values of a first plurality of leached polycrystalline diamond compact (PDC) cutters;

destructively testing wear resistance of each cutter of the first plurality to obtain calibration data;

23

brazing a second plurality of leached PDC cutters to the downhole tool, the first plurality and the second plurality being of the same type;
 after brazing, measuring a capacitance value of each cutter of the second plurality; and
 determining an estimated wear resistance of each cutter of the second plurality using the respective measured capacitance value of each cutter of the second plurality and the calibration data,
 wherein the capacitance value of each cutter of the second plurality is measured by:
 obtaining a capacitance measuring device comprising a positive terminal and a negative terminal;
 electrically coupling a first wire from the positive terminal to a leached layer of the respective cutter;
 and
 electrically coupling a second wire from the negative terminal to a surface of the downhole tool.
12. The method of claim **11**, wherein the first wire is electrically coupled by positioning a first conducting com-

24

ponent adjacent to and in contact with the leached layer of the respective cutter and the first wire.

13. The method of claim **12**, wherein the first conducting component is cylindrically shaped or annularly shaped.

14. The method of claim **12**, wherein the first conducting component is fabricated at least from a copper or copper alloy.

15. The method of claim **12**, wherein the first conducting component comprises a conducting material and an insulating material, the insulating material surrounding at least a portion of the perimeter of the conducting material.

16. The method of claim **11**, wherein the second wire is electrically coupled by positioning a second conducting component adjacent to and in contact with the surface of the downhole tool and the second wire.

17. The method of claim **16**, wherein the second conducting component comprises a foil.

18. The method of claim **16**, wherein the second conducting component is fabricated at least from a copper or copper alloy.

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